Review comments on "Hydrogeologic Evaluation of Proposed Leque Island Restoration", by Pacific Groundwater Group

The Pacific Groundwater Group (PGG) conducted a groundwater monitoring and flow modeling study to evaluate whether the removal of the dikes in Leque Island would result in the reversal of present groundwater flow directions and increased potential for salt water intrusion into the sea-level aquifer in the adjacent Camano Island. Observed groundwater water levels indicate that groundwater flow direction is currently in the easterly direction from the highlands at the northeast margin of Camano Island toward the lowlands and Davis slough. Leque Island is a small marshland bounded by the West Pass and South Pass of the Stillaguamish River on the east, Davis Slough on the west, Skagit Bay on the north and Port Susan Bay on the south. Davis Slough separates Camano Island from Leque Island. The easterly flow of groundwater from Camano Island toward Leque Island is consistent with the landscape topography and does not come as a surprise due to the existence of the surface water discharge features at the low lands, such as Stillaguamish River (South and West Pass), Davis Slough, and the various ditches constructed to drain lowland areas.

PGG evaluated the hydrogeological framework of the study area based on maps of surficial geology, soils, reports, and interpretation of geologic logs from other sources. PGG logged and oversaw installation of 8 monitoring wells on the project monitoring site. Geologic logs compiled for the project were used to construct 3 hydrogeologic cross sections through the study area. PGG monitored groundwater elevations in the 8 monitoring wells and 3 nearby private wells in the time period between November 2011 and September 2012 to develop synoptic groundwater elevation maps and groundwater level maps. All water levels were corrected for density of the brackish water within the well screens, so that plotted or mapped water levels portray freshwater heads calculated at the well screen. PGG also sampled 4 monitoring wells to evaluate variations in salinity. Two groundwater flow models (two dimensional and quasi-three dimensional) were constructed using MODFLOW modeling package to evaluate potential impact of Leque Island periodic inundation on annual average water table elevation beneath the island, and to predict how increased groundwater levels beneath Leque Island will affect groundwater flow and saltwater intrusion potential along the eastern edge of Camano Island.

Three-day averaged groundwater levels for the time period (Jan-Sep 2012) show decreased water levels (head gradient) from the eastern edge of Camano Island toward the ditch drained monitoring site and Davis slough, and generally higher heads than in Leque Island. This reveals eastward groundwater flow directions, at least toward the lowlands. Measured heads at two depths at wells N2 and S1 show negative head gradient and upward groundwater flow; thus, indicating that ditch drained site is a groundwater discharge area. Similarly, one would expect that Davis Slough and drainage ditches in Leque Island are also groundwater discharge areas. The ditches penetrate below the water table and generally have water-level elevations below the surrounding groundwater levels. PGG monitored electrical conductivity (EC) of groundwater in monitoring-site wells between late November 2011 and early May 2012. Although probe failures resulted in an EC monitoring record shorter than the groundwater level record, estimated salinity (0.6 EC) revealed relatively high groundwater salinity at the monitoring site, decreased salinity with depth and low EC/salinity at the sea-level aquifer beneath Camano Island uplands ("Aquifer D"). PGG attributes the brackish shallow groundwater at the monitoring site to have been caused by a combination of seawater recharge during inundation events, concentration of salts due to evaporation of shallow groundwater, and deposition of salt spray. The reduced salinity at depth may be attributed to mixing (dilution) with upwelling fresh groundwater in the low land and fresh groundwater discharge in the uplands. The hydrodynamic model predicted salinity in the Leque Island during inundation will remain below 10 ppt most of the time, a value which is close to the measured salinity of approximately 11 ppt at the Leque ditch. Hence, post-restoration groundwater salinities on Leque Island are expected to show little change from current salinities.

The local (two-dimensional) Leque Island GW model simulated an anticipated post-restoration inundation scenario of groundwater level rise between two drainage channels separated by a distance of 500 ft and subject to recharge rate calculated on the basis of saturated conductivity of the soil (silty clay loam), hydraulic gradient, and flood duration. A new drainage network is postulated to evolve as an outgrowth of periodic tidal flooding and ebbing within the pre-existing natural channel. Although the analysis to predict the final distribution of the drainage network involves considerable uncertainty, it is surmised that drainage network so restored will be relatively deeper and with higher drainage efficiency relative to the present ditch network. In other words, it is anticipated that improved drainage efficiency would alleviate otherwise potentially higher groundwater recharge and mounding caused by flooding. The period and extent of inundation caused by removal of existing dikes was modeled by Battelle using a hydrodynamic model, and the model output predicts that the land surface will be inundated an average of 5 hours per day during high tide conditions. Assuming a hydraulic gradient of 1 and 5 hours of inundation per day, the capacity for groundwater recharge was estimated to range from 0.3 to 1.0 in/day (100 to 365 in/year), far higher than the less than 8 in/year precipitation recharge estimated by the USGS on Whidbey and Camano Islands. Given the latter maximum precipitation recharge, inter-annual variability of precipitation recharge is expected to be of much less importance than the increased recharge initiated by post restoration tidal inundation of Leque Island. The USGS estimates of recharge rates revealed a small area on the southeast corner of the northeast lobe that had an estimated precipitation recharge rate of 18.3 in/yr. Although no explanation to such relatively high recharge rate is given in the report, this maximum precipitation recharge rate may be attributed to beach sand and colluvium from glacial outwash that are associated with a relatively high hydraulic conductivity. The three-dimensional GW flow model predicted a groundwater mound coinciding with this high recharge area, and the GW mound in this vicinity appears to contribute to a hydraulic barrier in addition to higher heads in the uplands, which altogether create a hydraulic buffer against potential impact of elevated groundwater water levels in Leque Island caused by the post restoration inundation. The two-dimensional leque Island model predicted 6.92 ft (NAVD88) as the long-term average of groundwater level beneath the island, i.e. 1.2 ft higher than under the current condition and 0.08 ft below average ground surface elevation at Leque Island (7 ft NAVD88). The anticipated rise in the groundwater water level was used as a fixed-head boundary condition in the quasi-three dimensional model to predict groundwater flow directions during post-restoration inundation. In the quasi-three dimensional model, the stages of the “Drain” boundary condition for deeper cells exposed to submarine water were adjusted for the density of seawater to yield equivalent fresh water values. The steady-state water levels simulated by the calibrated MODFLOW model reveal higher heads in the upland declining gradually toward Skagit Bay and Port Susan Bay, but most importantly toward the Camano lowland and Davis Slough. The flow directions from the Camano upland toward the ditched Camano Island lowland (monitoring site) remained unaltered, but with a westerly flow from the Leque Island toward the Davis Slough and drainage ditches at the monitoring site. In other words, the ditched Camano

Island lowland appears to be a groundwater discharging site (Fig. 5-3). Uncertainty in both groundwater flow models were accounted for but in a nonconventional form. The selected aquifer hydraulic conductivity values (K) in the two-dimensional, cross-sectional groundwater flow model were considered conservatively high so that higher groundwater levels are simulated as a result of post-restoration inundation. Uncertainty in the 3-D groundwater flow model was also accounted for using 4 different models. The four models were constructed using two likely hydrogeologic interpretations and two degrees of hydraulic connection between shallow groundwater beneath the Camano Island to immediately adjacent surface-water features. The greater these hydraulic connections, the greater the extent to which increased post-restoration heads beneath Leque Island will be intercepted and relieved due to increased discharge to these features, and will therefore have a lesser effect on Camano Island.

The bullets below are recommendations that address key concerns about the PGG modeling study. Most of the concerns could be addressed by conducting additional model simulations:

- It should be stressed that salt water intrusion was not simulated directly. Rather, a groundwater flow model was developed with the premise that non- reversal of groundwater flow underneath northeast margins of Camano Island acts as a barrier to salt water intrusion potential following the Leque Island restoration.

- 8 wells were involved yet only one pump test analysis was conducted to estimate aquifer hydraulic properties. More precise inferences on aquifer properties might lead to improved model calibration. Limited data precluded a thorough model calibration, and the adopted calibration goals were somewhat subjective and qualitative. However, to address the lack of direct in-situ measurements of aquifer properties (hydraulic conductivity, specific storativity, specific yield), these parameters were instead inferred from soil and formation sediment textures obtained from the interpretation of geologic logs from wells and borings, and then by tweaking the inferred values during calibration. While this is an acceptable modeling practice, ground-truth values of aquifer properties would have been useful. It should also be noted that the USGS has previously estimated aquifer properties beneath Camano Island during development of groundwater flow models for Island County (Sapik et al., 1998 cited in the PGG report). Modeled K estimates for Aquifer D on the northeast lobe of Camano Island were relatively high (540 ft/d). Higher end values for K used in the present (PGG) groundwater flow model for Aquifer D were almost similar and as high as 545 ft/d.

- The calibration period involved a one year record of observed water levels and a snapshot of head gradients (at two locations only); this was not sufficient to account for inter-annual climate and groundwater flow variability. Furthermore, by simulating steady-state flow at annually-averaged conditions, seasonal variations of groundwater levels were overlooked. A thorough calibration of the groundwater flow model for the Leque Island would have been possible using the high resolution water levels data, on the other hand, however, the incremental gains by a rigorously calibrated model would unlikely predict a reversed groundwater flow direction beneath Camano Island. Although model calibration was not rigorous, the performance evaluation metrics were sufficient given the data limitation and consistently pointed toward a successful model calibration. Not accounting for inter-annual variability is expected to have a minimal impact on post-restoration modeling results, because as mentioned above groundwater recharge caused by periodic Leque inundation (100-365 in/yr) is estimated to be much higher than the rainfall-recharge values estimated by the USGS (ranging from 0-18.3 in/yr).

- Postulated formation of the post-restoration drainage network, its geometric characteristics and drainage efficiency pose some uncertainty. EPA recommends that additional models be run to answer the following question: What will the impact on groundwater levels be if the drainage ditches are not formed as would be expected or with much less drainage efficiency?

- The assumption that "all residential and irrigation removal from Aquifer D entirely recharge the same aquifer" may underestimate drawdown of water levels around existing residential wells. This may be a concern during the season of low groundwater levels and none wet years. Higher than the assumed pumping rate (9 gpm) may be examined in an additional, conservative model simulation. It is EPA's understanding, however, that currently wells have been relocated to inland with the overall pumping withdrawals spread among a larger number of wells. The impact of additional pumping to meet future growth on lowering the groundwater level on Camano Island remains a threat to potential saltwater intrusion.

- EPA also recommends that scenarios of inundation longer than 5 hrs per day (e.g., 6 or 7 hours) be used in a follow-up model simulation as a conservative scenario to account for potential higher water table under Leque Island caused by longer inundation times.

In summary, it is impossible to state that saltwater intrusion will not occur in localized areas with absolute certainty, but the groundwater modeling approach was carried out based on sound science given the data and information. Particular aspects of the model could be scrutinized, but it is highly unlikely that any further model modifications would alter modeling results significantly to the extent that the conclusion of the study would be different. Additional model simulations are recommended to explore conservative scenarios outlined above. Worth noting also is that scant details were given about the Battelle hydrodynamic model and its predictive uncertainty. Given the data limitation and budget constraint, overall, a sound modeling approach was implemented on the presumption that PGG obtained fairly accurate and annually representative groundwater level measurements, and that correct account for salinity density conversion were made throughout the study area. Because the salinity predicted by the hydrodynamic-model at Leque Island is not different from the observed levels, and that the observed eastward groundwater flow beneath northeast Camano Island is not predicted to be reversed considering the simulated post restoration Leque Island inundation, the threat of increased salinity and westward saltwater intrusion to the west of the ditched Camano Island lowland appears to be unlikely on average.